A Way to Measure the Residual Flow in the Lim Fjord

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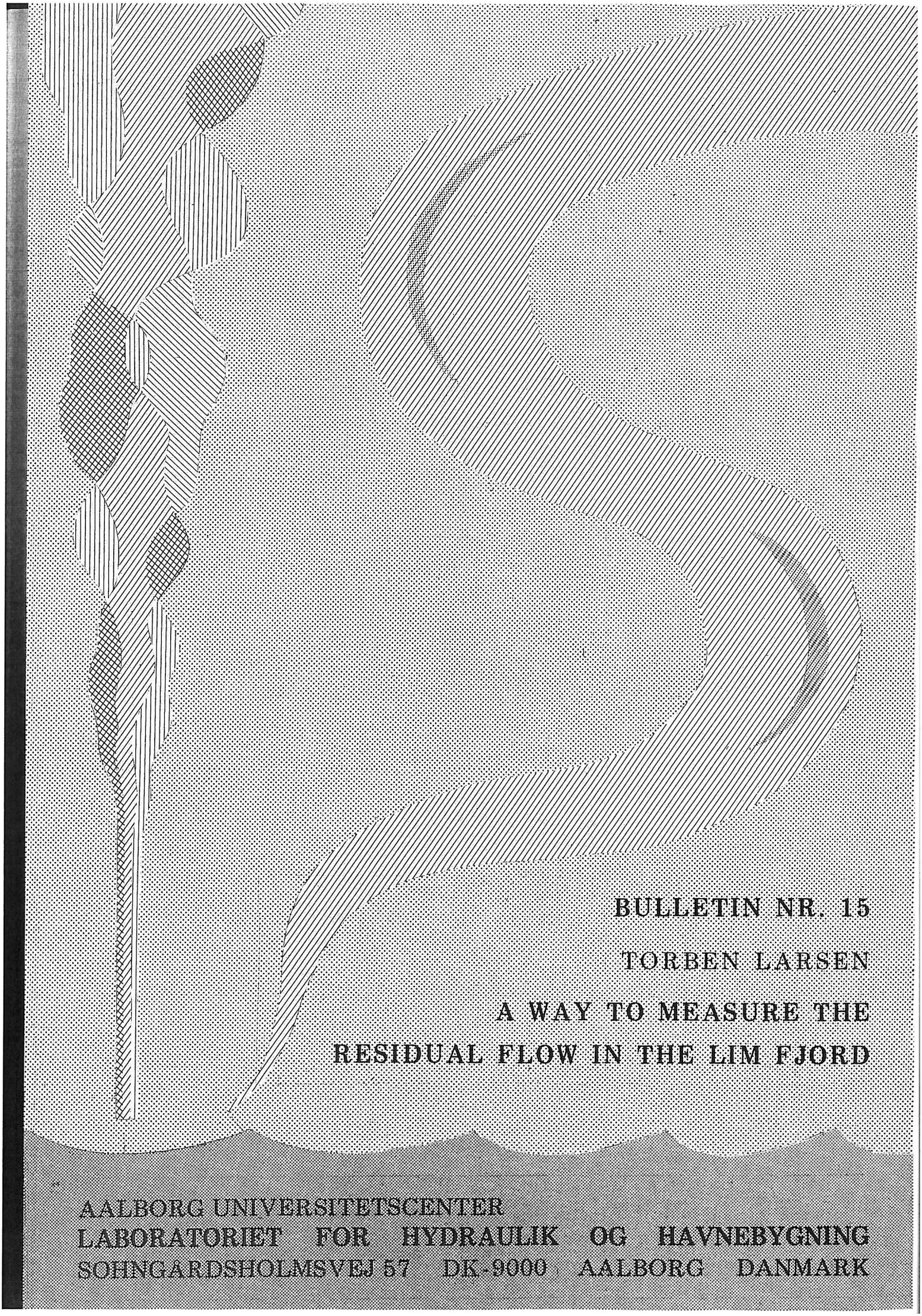

BULLETIN NR. 15

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A WAY TO MEASURE THE RESIDUAL FLOW IN THE LIM FJORD

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The paper appears as a short version of the former bulletin no. 11 "Bestemmelse af Limfjordens nettostrøm" (Determination of the residual current in the Lim fjord).

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A WAY TO MEASURE THE RESIDUAL FLOW IN THE LIM FJORD - DENMARK

by

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ABSTRACT

The Lim fjord in Denmark has two connections to the open sea. Therefore the residual flow through the Lim fjord is an important parameter in relation to salinity and concentration of nutrients. It is described how it has been possible to determine the residual flow from the observation of the duration of the tidal current going the same direction.

The purpose of the paper is to present the idea behind this field measurment technique and not to publish oceanographic data.

A SHORT DESCRIBTION OF THE LIM FJORD

The Lim fjord is in the northern Jutland in Denmark. As well as the rest of the danish landscape the fjord was formed in the glacial time. The length of the fjord is 170 km, the surface area is 1500 square km and the average depth is 6 m. Maximum depth is 28 m. (See Figure 1 and 2).

Since historic time the fjord has been in connection with the Kattegat to the east. But at least from the viking age the fjord has been separated from the North Sea to the west. In 1825 a flood in the North Sea

opened a channel between the fjord and the sea. After some decades with unstable conditions the channel stabilized its course at Thyborøn. This dramatic event forced total changes in salinity and biological environment in most of the fjord.

Due to the small water depth in the fjord only insignificant vertical salinity gradients occur in the main course. Therefore the transport of soluble matter is depending only on the residual flow and the dispersion. For most of the fjord the residual flow has the most important transport effect.

The environmental problems in the fjord occur most significant in the secondary fjords where the residual current do not pass. All the secondary fjords have the typical undesirable eutrophic state, which also can be observed in a number of danish fjords. The influence of the residual flow in the level of nutrients in the secondary fjords is indirect but important. The residual current in the fjord is responsible for the concentration level in the main course and define the boundary concentration level for the secondary fjords.

On average over the year the residual flow is running eastward with a value of 50-100 cubic meter per second.

THE BACKGROUND FOR MEASUREMENT OF THE RESIDUAL FLOW

The water exchange in the Lim fjord is primarily depending on the water levels in the North Sea and the Kattegat and on the wind. But also the waterlevels in the North Sea and the Kattegat depend most on the wind, and former investigations [1] show that the residual current is well correlated to the wind vector along the fjord. The correlation is surprisingly significant for moderate to strong winds, but for light winds this emperical correlation shows not to be applicable. The physical reason for this is the wellknown fact that the friction factor between wind and water surface during light winds is not well defined.

In northwest Europe light winds are often connected with high pressure, easterly winddirection and high temperature, and occur typically in the sping and summer. Those conditions are also the most critical from the point of wiev of water quality.

Current measurement in the Lim fjord using conventional automatic current meters is difficult during the summer due the large amount of flowing sea-weed. A dayly control of the currentmeter is necessary but even so the record is often interrupted. In the following is presented a simple method to find the residual flow from observation of the current direction.

THEORETICAL RELATION BETWEEN TIDAL EXCURSION AND DURATION

As a rough approximation current measurements at Aalborg (Fig. no. 3) shows that the one dimensional current in the fjord can be simplified as (see Fig. no. 4):

$$U = U_t \cos\left(\frac{2\pi}{T} t\right) + U_n \qquad (1)$$

U actuel currentvelocity (average over crosssection)

U_t amplitude in tidal current (average over 28 days is 0,44 m/s near Aalborg)

T tidal period (M_2-component 12,42 hour)

t time

U_n residual current

We now define the way of current or the current excursion V as (Fig. no. 4)

$$V = \int_{t_o}^{t_o + T_u} u \, dt \qquad (2)$$

where T_u is the period in which the current is going the same direction.

Combining (1) and (2) gives

$$\frac{V}{U_t T} = \frac{1}{\pi}\left[\sin\left(\pi \frac{T_u}{T}\right) - \left(\pi \frac{T_u}{T}\right) \cos\left(\pi \frac{T_u}{T}\right)\right] \qquad (3)$$

As a practical approximation (3) can be developed as

$$\frac{V}{U_t T} = 1{,}60 \left(\frac{T_u}{T}\right)^{2{,}63} \qquad (4)$$

It is now postulated that the way of current V can be determined from (4) using observed values of T_u.

This version of the method neglect the influence of the variation of the water level during the tidal period. For the Lim fjord at Aalborg this is a reasonable approximation. The tidal range is 0,3 m and the average depth is 11 m where the current measurements were carried out.

CALIBRATING THE METHOD BY MEASUREMENTS

During 1971 the Royal Danish Hydrographic Office had an automatic current meter placed under one of the bridges crossing the Lim fjord at Aalborg, and during 1974 the author continued the measurements on the same position. It should be interposed that most of the velocity measurements where inapplicable because of the flowing seaweed.

Among those intact measurements 72 periods have been chosen to calibrate the method. The periods has been chosen from days with moderate to light winds. In Fig. no. 5 the results are shown. A curve fitting gives

$$V = 4{,}84\ 10^{-4}\ T_u^{2{,}08} \qquad (V \text{ in cm and } T_u \text{ in sec}) \qquad (5)$$

or if inserted T = 12,42 hour and U_t = 0,44 m/s

$$\frac{V}{U_t T} = 1{,}16\ \left(\frac{T_u}{T}\right)^{2{,}08} \qquad (6)$$

Comparing the theoretical equation (4) with the emperical equation (6) shows

T_u hour	$\frac{V}{U_t T}$	
	(4)	(6)
2	0,01	0,02
4	0,11	0,08
6	0,26	0,24
8	0,47	0,50
10	0,74	0,90

The agreement seems satisfactory. Moreover it can be mentioned that it has been statistically tested if it was possible to distinguish between two different equations for the relation (6), one for eastgoing current and one for westgoing current; but the test was not able to show significant difference.

COMPARING MEASURED RESIDUAL CURRENT AT LØGSTØR BY ESTIMATED RESIDUAL CURRENT AT AALBORG

Fig. no. 6 illustrate by an example the results of estimating the residual current by the method described in this paper compared to some direct measurments carried out in an other connection [1] near Løgstør, which is 50 km from Aalborg. Due to fresh water inflow to the Lim fjord between Løgstør and Aalborg and due to the effect of the storingcapacity the residual flow can not be expected to be exactly the same in Aalborg and Løgstør if a small timescale as a tidal period is used.

Whatever that can be said in the accuracy of the method, it has shown to be the only practical and economical way for the moment to observe the residual flow in the Lim fjord during longer periods.

ACKNOWLEDGEMENTS

The Research Committee of University of Aalborg has surpoted this work. The writer thanks his students Mr. Niels Einar Jensen and Mr. Ervin Pedersen for handling the large amount of data.

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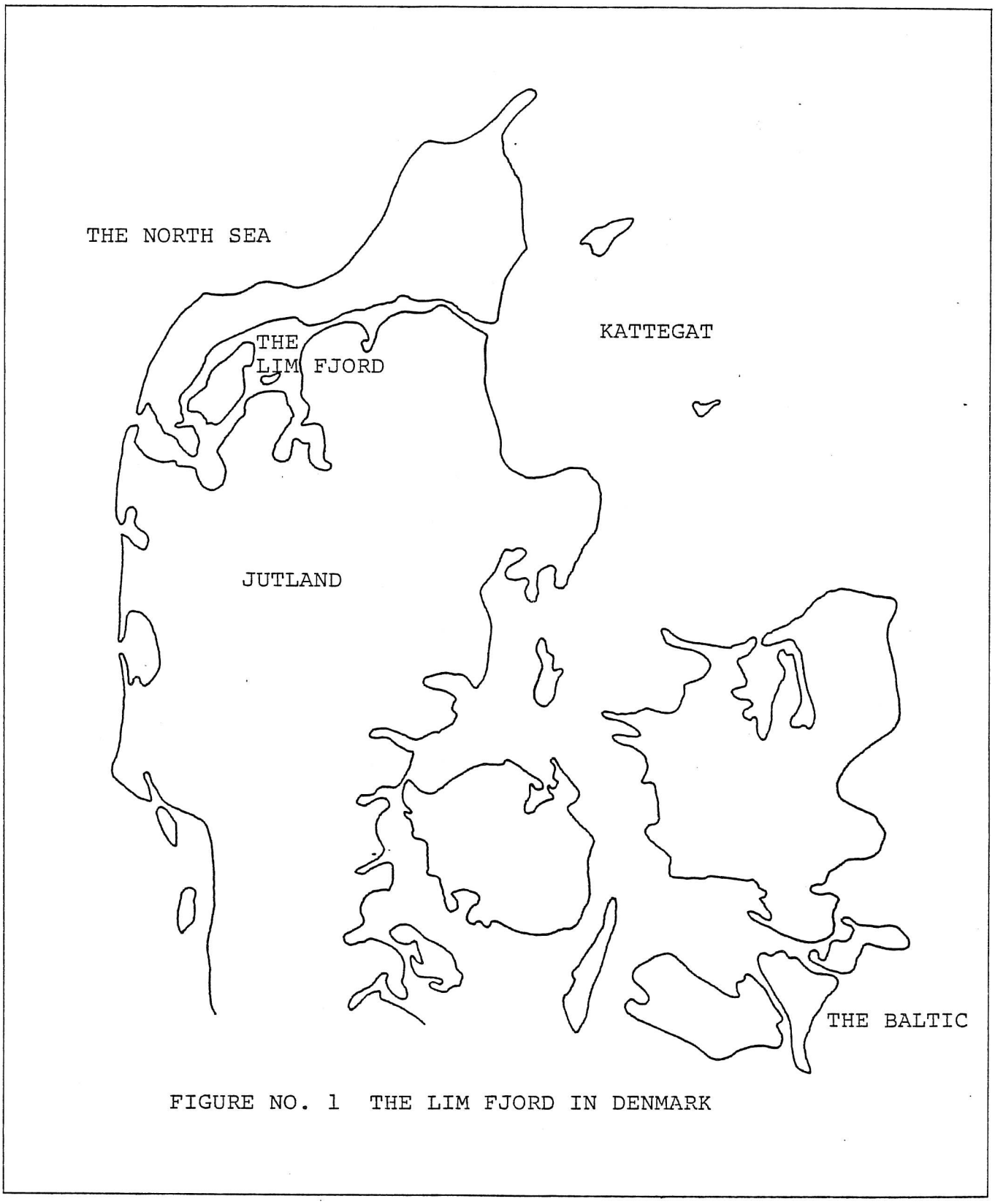

FIGURE NO. 1 THE LIM FJORD IN DENMARK

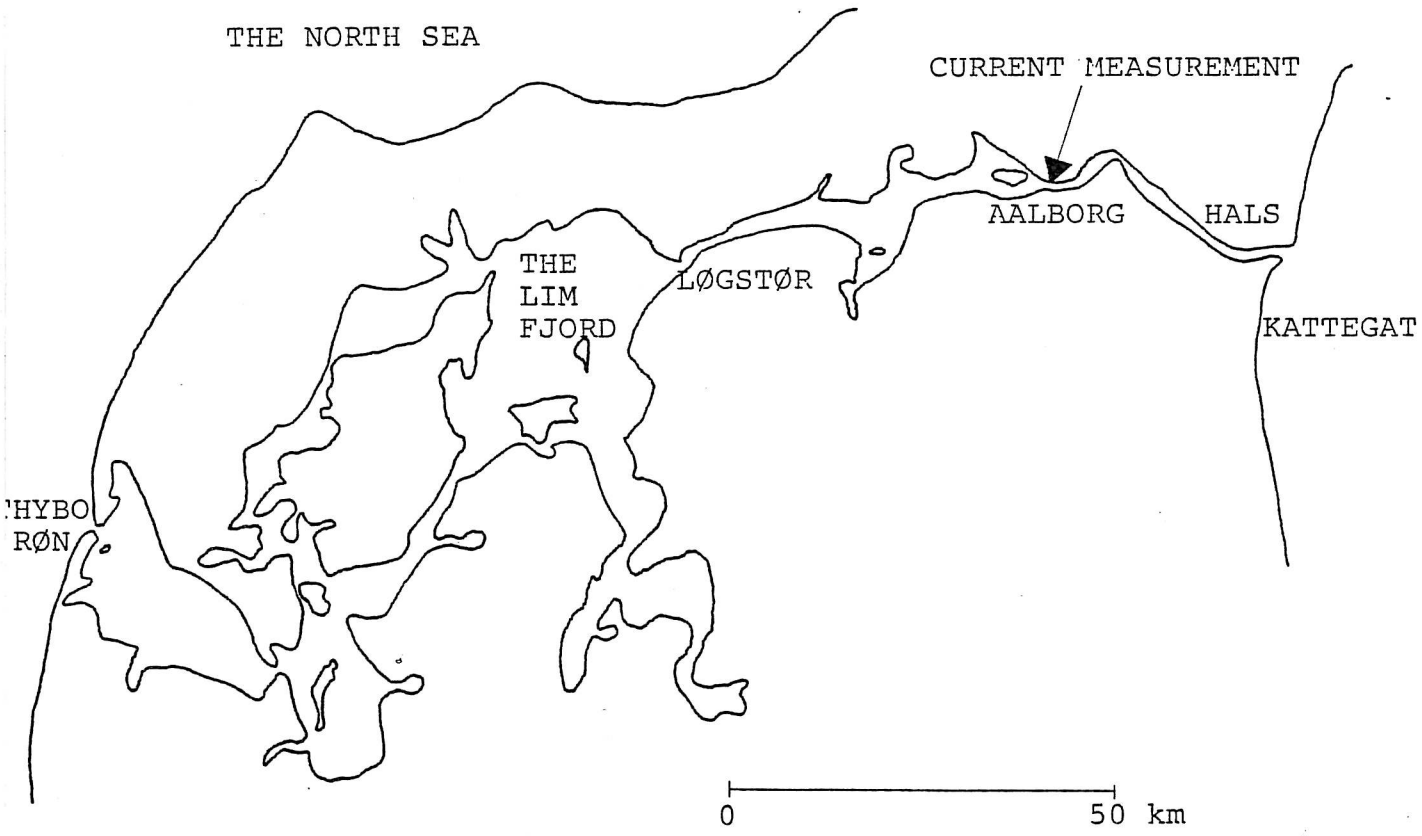

FIGURE NO. 2 THE LIM FJORD

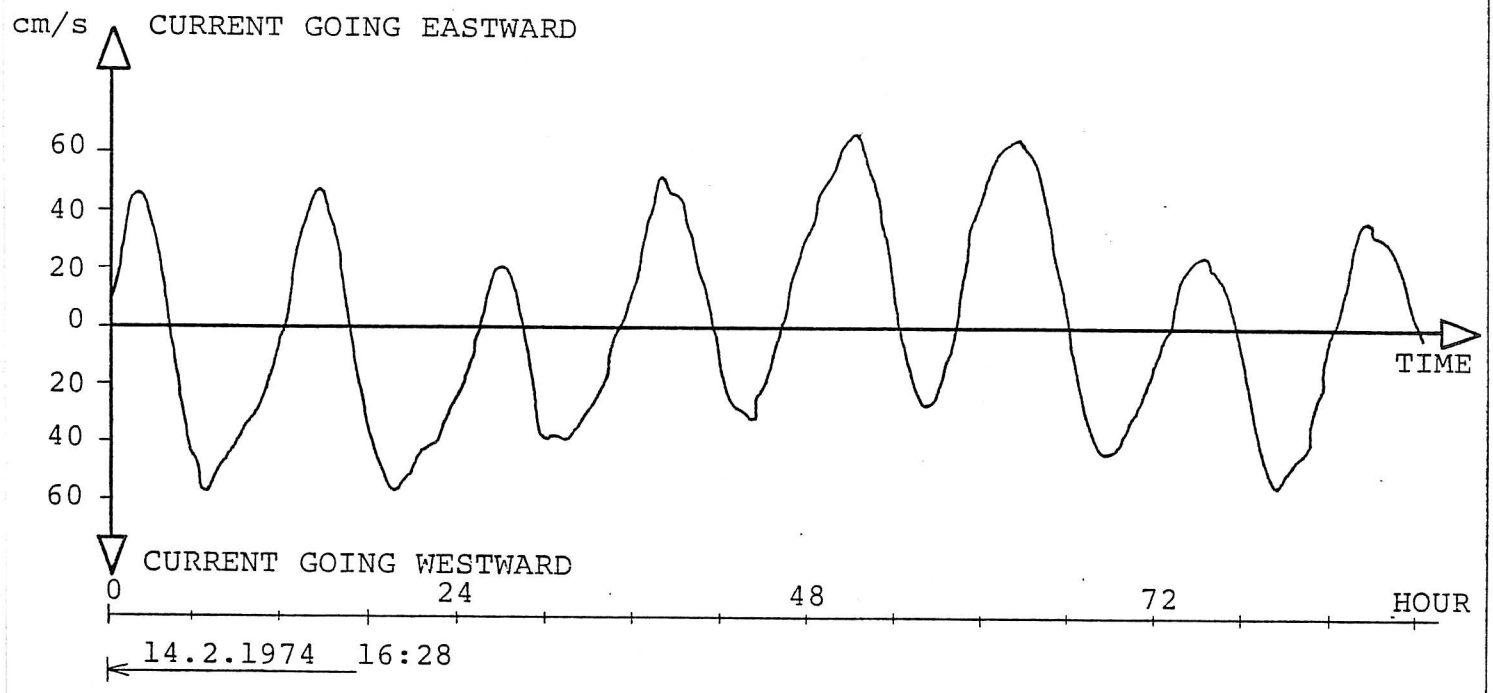

FIGURE NO. 3 SELECTED PART OF CURRENT MEASUREMENTS AT AALBORG

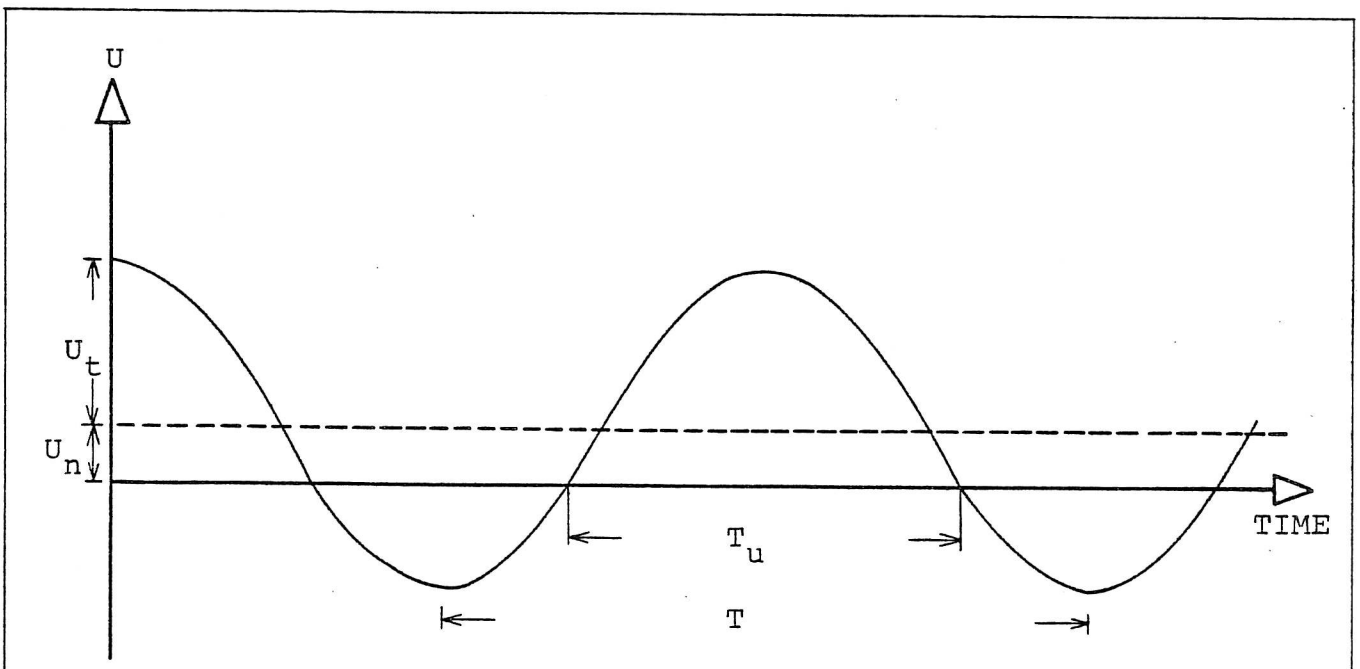

FIGURE NO. 4 THEORETICAL TIDAL CURRENT AND RESIDUAL CURRENT

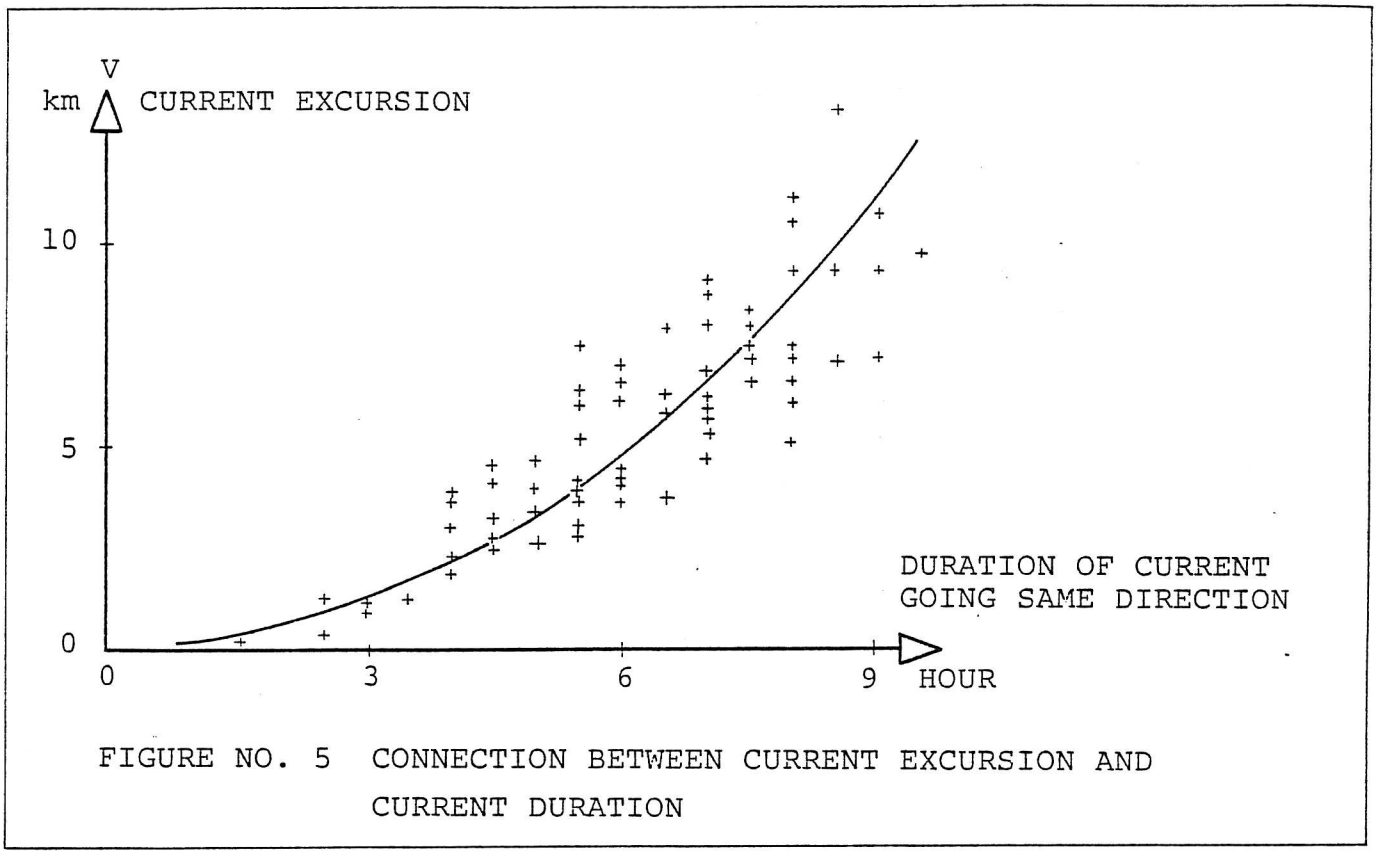

FIGURE NO. 5 CONNECTION BETWEEN CURRENT EXCURSION AND CURRENT DURATION

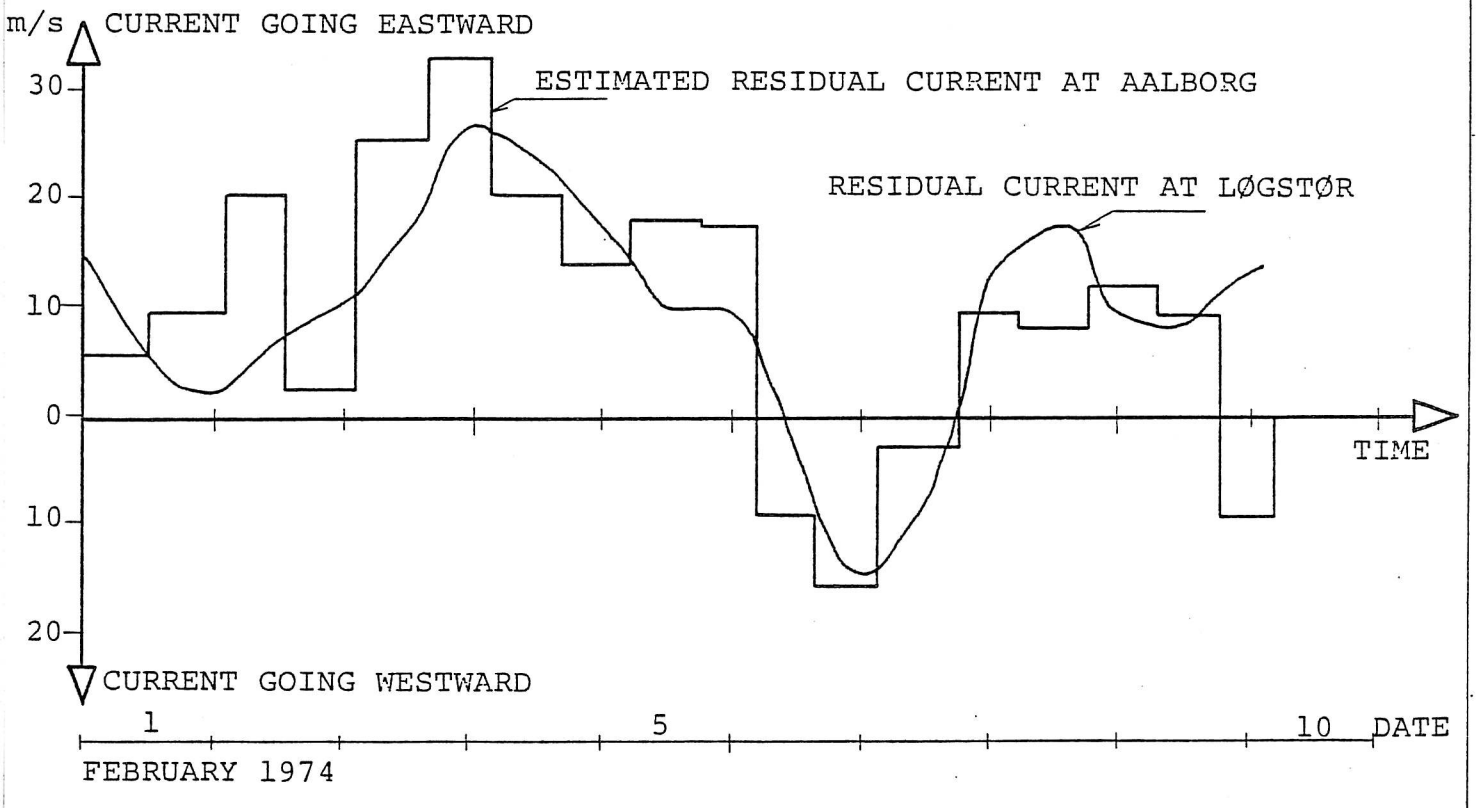

FIGURE NO. 6 COMPARISON BETWEEN MEASURED AND ESTIMATED RESIDUAL CURRENT